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RIVERBED EROSION ESTIMATION IN THE SELECTED CROSS-SECTIONS OF THE UPPER VISTULA RIVER

Marta Łapuszek
Cracow University of Technology

Summary

The analysis of time variability of riverbed elevation recorded at eight cross-sections of the Upper Vistula River is presented in the paper. The variability is analyzed on the base on the observed low annual water stages and the cross-sectional geometry variation observed over decades. Furthermore, the analysis of riverbed changes in the years 2001 – 2011 was done in 16 cross-sections located between the Koło and Zawichost gauging stations.

Based on the analyzed changes in the riverbed elevation of the eight tested gauging stations it should be noted that since the beginning of the observation period, that is from about the beginning of the 20th century to the mid 1960's, in the Upper Vistula River riverbed erosion can be observed with a slight tendency for accumulation. As a result of technical regulations of the river channel of the Vistula River from km 247 +000 to 295 +000 carried out in the years 1975 to 1982, intensive processes of riverbed erosion has occured. In most of the 16 profiles it was found that in the years 2001-2011 the river channel was deepened. The occurrence of local riverbed deepening at the river banks was also observed.

Key words: riverbed erosion, river regulation, Vistula River.

INTRODUCTION

The Upper Vistula channel has a natural tendency to deepening and change its location in plan. These changes are caused by the natural process of erosion, the intensity of which depends on the conditions dominant in the catchment area (geology, morphology, hydrological regime, climate). Therefore, the process of riverbed erosion varies.

The river channel, constantly affected by time-varying impacts of the water flow, is formed in a long time to obtain the hydrodynamic balance. Such a balance is achieved by the channel by adapting its geometry horizontally, transversely and along its course due to the current resistance to flow. River, in order to ensure the flow of water and sediment, constantly adapts its morphological characteristic (length, depth, slope, course) through the processes of erosion and sedimentation. It should be noted that this adaptation also determines the ecological dynamics and guarantees the richness of river habitats. However, attention should be paid to the situation where a noticeable change in the geometry of the river channel is no longer the result of processes that ensure the balance, but begins to exhibit the occurrence of disturbances in the hydrodynamic balance (high erosion or accumulation) [Bogardi J., 1978].

Riverbed erosion is often accelerated by anthropogenic factors. Riverbed erosion of the channel with movable bottom is often intensified by the exploration of sediment and hydro-technical activities. The paper presents the riverbed evolution observed in the last 100-year period in the studied gauging stations located on the river course between Szczucin and Zawichost on the upper Vistula River.

Riverbed erosion observed on these gauging stations is mostly caused by river regulation consisted in the shortening and narrowing of the river channel.

The studies are based on the variability of annual low water stages observed during the long term.

METHODOLOGY OF THE STUDY

The analysis of the variability of riverbed changes were done on the assumption provided by Punzet [1994], and proven by the author [Łapuszek M., Ratomski J., 2006], that minimal annual water stages correspond to the change of the riverbed level The series of minimal annual water stages of each studied gaging station is divided into time intervals. Then, in each time interval the function that describes the position of the bottom in a given year T is defined.

Function $H_i(T)$, which describes the time course of the annual water stages in the *i*-th interval is written as follows [Łapuszek M., Ratomski J., 2006]:

$$H_i(T) = H_{av}(T) + \varepsilon \tag{1}$$

gdzie:
ε - standard deviation of residual component;
$H_{av}(T)$ - regression function expressed by a linear function::

$$H_{av}(T) = E(H|T) = \alpha T + \beta \tag{2}$$

gdzie:
T - year of observation;
α - the rate of the intensity of erosion or accumulation, cm·year^{-1};
β - constant, cm.

The value of parameter α indicates the average annual lowering or agradation of the riverbed in year T. The symbol $E(H|T)$ is the conditional expected value of the minimal water stage in the minimum – T. The parameters a and b are estimated by the least squares method.

The changes in the location of gauging station and the position of gauging station datum were taken into account in the calculations. The calculation results were verified by analysis of changes observed in the measured geometry of cross sections. The archived and current cross-sections of channel were used for the verification [IMGW].

OBJECTIVE OF STUDY

The observations were made in the following gauging station of the upper Vistula River: Szczucin (years: 1887-2010), Otałęż (years: 1898-1960), Ostrówek (years: 1888-1960), Koło (years: 1898-1991), Dzików (years: 1870-1960, including intervals of data discontinuity), Sandomierz (years: 1904-2010), Dąbrowa Wrzawska (years: 1900-1960), Zawichost (years: 1904-2010) [IMGW]. Mentioned above gauging stations are located between km 194+000 and km 288+000 of the river course.

An analysis of cross-sectional geometry variation in the profiles of gauging stations Szczucin (years: 1936-2011) and Sandomierz (years: 1927-2006) was also carried out [IMGW]. The location of the studied gauging stations are shown in Fig. 1.

Additionally, in order to assess the impact of floods on the process of riverbed erosion, the analysis of the variability of 16 cross sections located on the Vistula River between km 241.500 and 285.000 was carried out. The comparison of cross-sectional geometry was made for years 2001 and 2011.

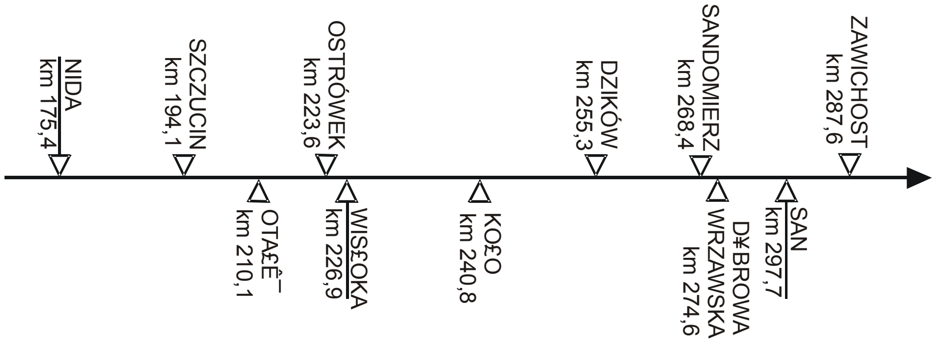

Figure 1. Location of the studied gauging stations on the Upper Vistula River.

RIVERBED EROSION ASSESSMENT

Analysis The riverbed erosion variability in eight gauging stations of upper Vistula River is analyzed on the base on the variability of minimum annual water stages observed during decades.

In the Szczucin gauging station riverbed erosion was observed during the years 1889-1934 and 1935-1943. Process of accumulation was observed in the years 1945-1980. In the years 1981-2010 in Szczucin intensive riverbed erosion was observed, the average annual bottom lowering was 2.5 cm. This process continues until the present (Fig. 2). In the Otałęż gauging station during the years 1898-1924 there was observed riverbed erosion (Fig.3). In the years 1925-1952 the river channel was stable. After 1960 the station was closed.

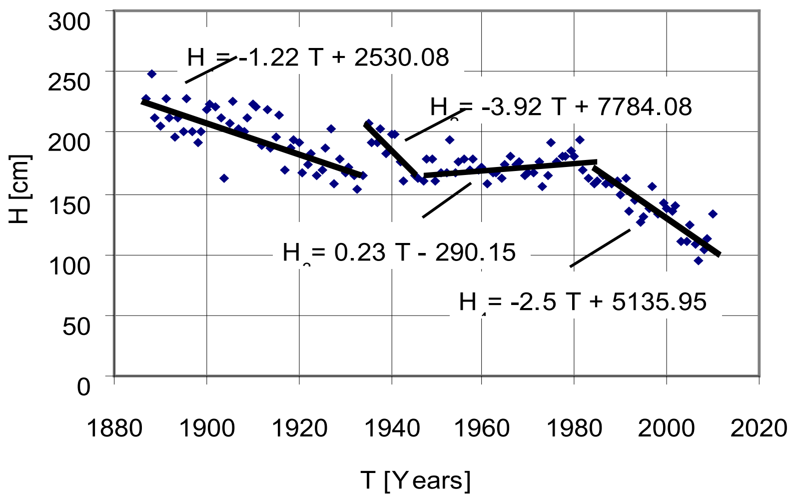

Figure 2. Variability of annual minimum levels and estimated linear trend at the Szczucin cross-section on the Vistula River.

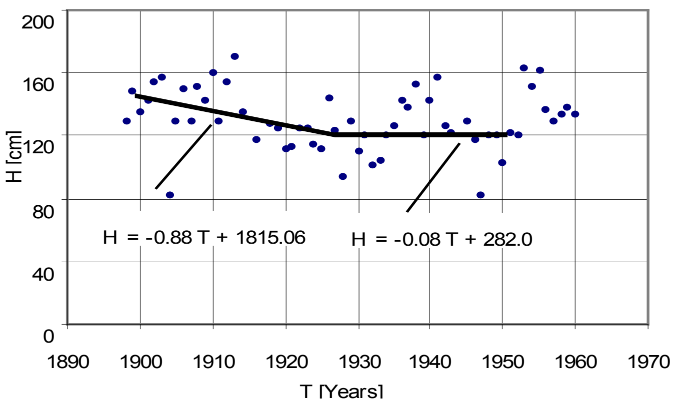

Figure 3. Variability of annual minimum levels and estimated linear trend at the Otałęż cross-section on the Vistula River.

In the Ostrówek gauging station the process of accumulation was observed during the years 1888-1916 and 1917-1960. Only at the years 1916-17 there was observed process of rapid, 50-cm, bottom lowering (Fig. 4). After 1960, the station was closed. In the Koło gauging station riverbed erosion was observed during the years 1898-1932. In the years 1933-1981 there was observed trend toward accumulation. In the years 1982-1991 process of high riverbed erosion was observed. The mean annual bottom lowering was 2.41 cm (Fig.5). In 1992 the station was closed.

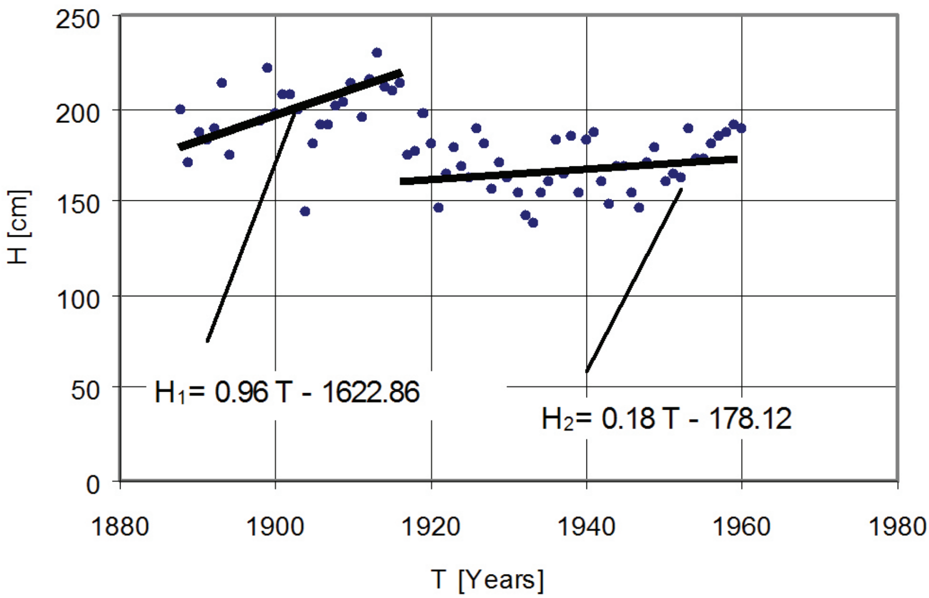

Figure 4. Variability of annual minimum levels and estimated linear trend at the Ostrówek cross-section on the Vistula River.

In the Dzików gauging station riverbed erosion was observed at the period of 1889-1949. In the years 1956-1960 there was observed process of slight accumulation (Fig.6). After 1960, measurements of water stages in the gauging station were discontinued. In the Sandomierz gauging station in the period of 1904-1914 there was observed trend toward accumulation. During the years 1919-1980 in Sandomierz the proces of riverbed erosion was observed. In 1981-2010 the process of slight erosion is observed, and continues to the present (Fig.7).

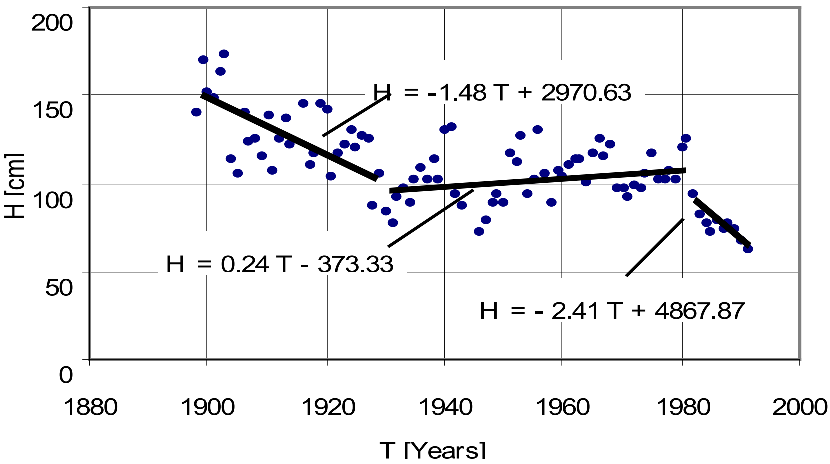

Figure 5. Variability of annual minimum levels and estimated linear trend at the Koło cross-section on the Vistula River.

In Dąbrowa Wrzawska during the period of 1900-1922 high process of riverbed erosion was observed, the mean annual river bottom lowering was 1,89 cm. In the years 1923-1943 there was observed process of accumulation. During the years 1948-1960 the river channel was almost stable, and slight accumulation was noticed (Fig.8). After 1960, measurements of water stages in the gauging station has been discontinued. In Zawichowst gauging station the process of accumulation was noticed in the period of 1904-1941. In the years 1942-1981 and 1982-2010 riverbed erosion is observed, and continues to the present (Fig.9).

Additionally, based on the measured geometry [IMWM-Krakow], the analysis of the cross-sectional variation in two gauging stations: Szczucin and Sandomierz was carried out. These are the profiles where hydrological observations are carried out to the present.

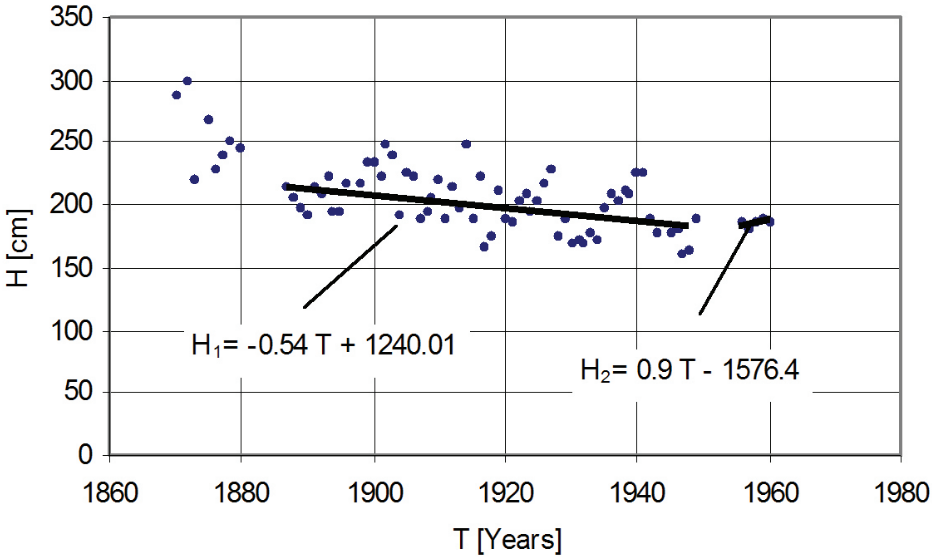

Figure 6. Variability of annual minimum levels and estimated linear trend at the Dzików cross-section on the Vistula River.

In the Szczucin gauging station the variability of cross-sectional geometry of the years 1936-2011 was analyzed (Fig.10). These observations show that the river channel is stable in the horizontal direction. In the vertical direction a slight tendency to riverbed erosion is observed. This process is also observed in the variability of the minimum annual water states during the years 1887-2010 (Fig. 2). In the Sandomierz gauging station the analysis of the variability of geometry of the years 1927-2006 was carried out (Fig.11). In the horizontal direction the river channel is stable. In the years 1983-2006 process of riverbed erosion was noticed. This process is also observed in the variability of the minimum annual water states in years 1980-2010 (Fig.7).

Moreover, the variability of riverbed evolution was carried out on the Upper Vistula River course between the Koło and Zawichost gauging stations in years 2001-2011 (Fig.10, Fig.11). The aim of the comparison was to examine the impact of floods that appeared in the last decade (2001, 2006, 2010) with respect to the process of riverbed erosion (Fig.12, Fig.13). Here below are examples of two of the 16 measured cross-sections.

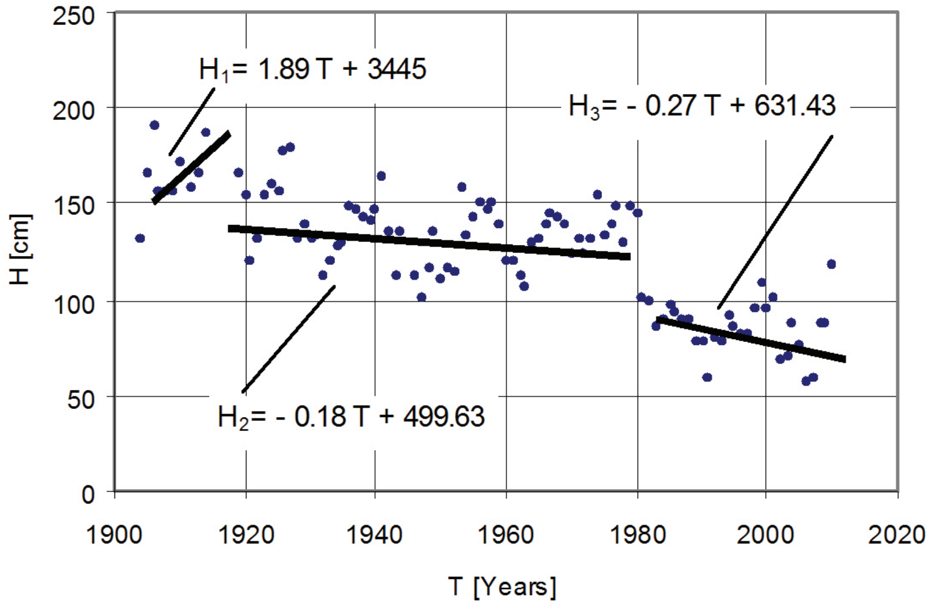

Figure 7. Variability of annual minimum levels and estimated linear trend at the Sandomierz cross-section on the Vistula River.

In most of the cases highly variable geometry as a result of the sediments movement was observed in the cross-sections with dunes. This process is strong at kms: 249+000, 264+000, 266+300 and 273+000. In several studied cross-sections local significant deepening at the river banks were noticed. The magnitude of these depressions reached up to 1.8 m at the cross-sections located at kms 259+300, 268+000, 274+800 of the river course. The eroded sediment is deposited on floodplain terraces just above the convex banks, as it is observed at the cross-sections located at kms 247+700, 259+300, 264+000, 274+800 and 276+800 of the Vistula River course.

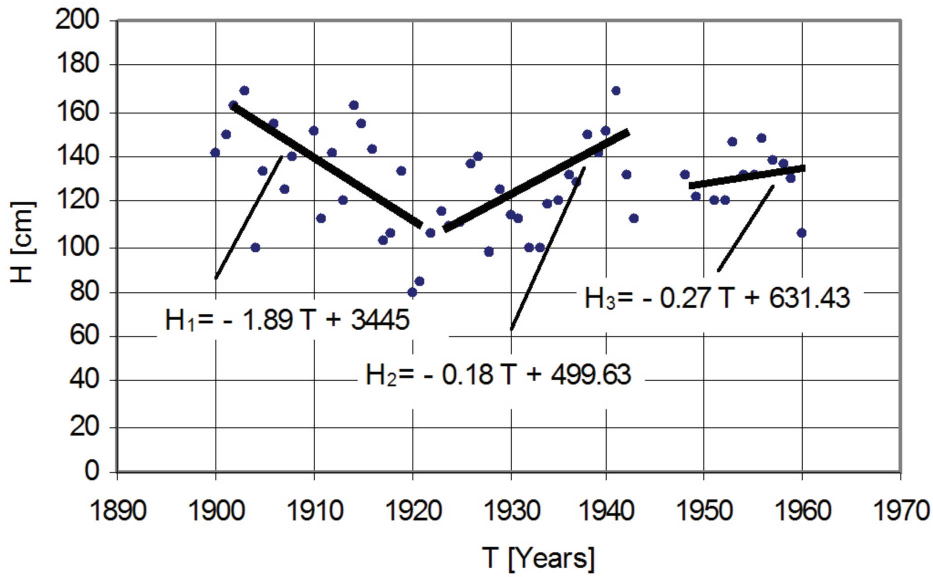

Figure 8. Variability of annual minimum levels and estimated linear trend at the Dąbrowa Wrzawska cross-section on the Vistula River.

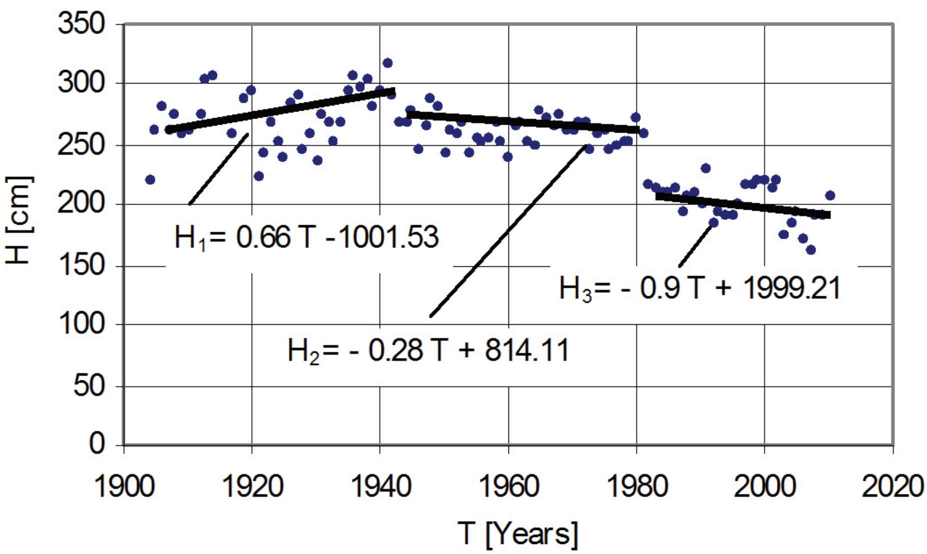

Figure 9. Variability of annual minimum levels and estimated linear trend at the Zawichost cross-section on the Vistula River.

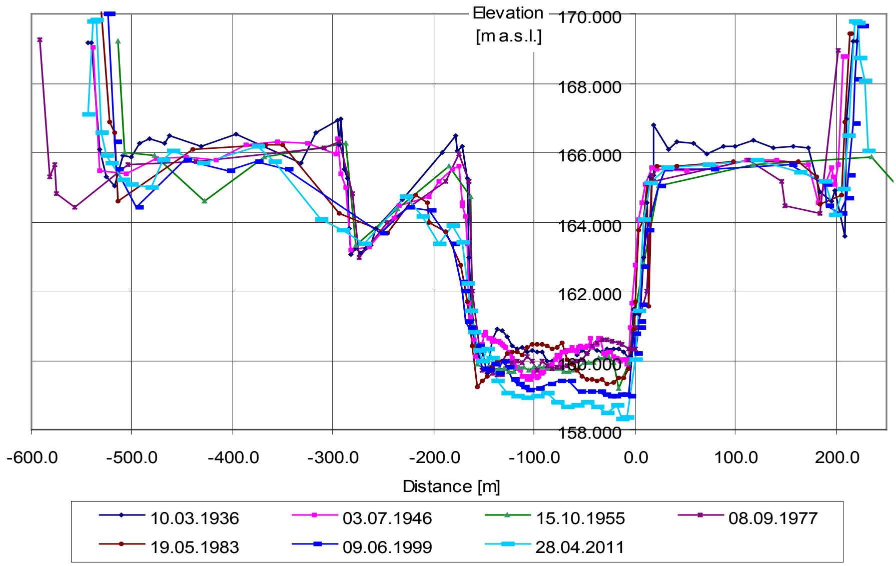

Figure 10. The channel geometry development in 1936-2011 at the Szczucin cross-section on the Vistula River [IMGW].

RESULTS ANALYSIS

On the basis of the minimum annual water stages analysis of the eight gauging stations of upper Vistula River it should be noted that since the beginning of the observation period, that is from about the beginning of the 20th century to the mid 1960's, riverbed erosion can be observed with the slight tendency to accumulation.

The process of riverbed erosion went in different ways in each of studied gauging stations. In the Szczucin gauging station since 1889 until 2010 the riverbed was lowered up to 1.2 m. In the years 1933-1991, the riverbed in the Koło gauging station was lowered up to 0.8 m as a result of erosion, also in Dzików the same process was observed. In the Otałęż gauging station the proces of slight erosion was noticed, and the river channel was stable from 1920 until the end of the observation period. In the Ostrówek process of accumulation was observed , and since 1915 when the riverbed was lowered down to 0.5 m the channel was stable until the end of the observation period. Only in Dąbrowa Wrzawska the erosion was observed in the years 1900-1921, and from 1922 to 1960 the accumulation.

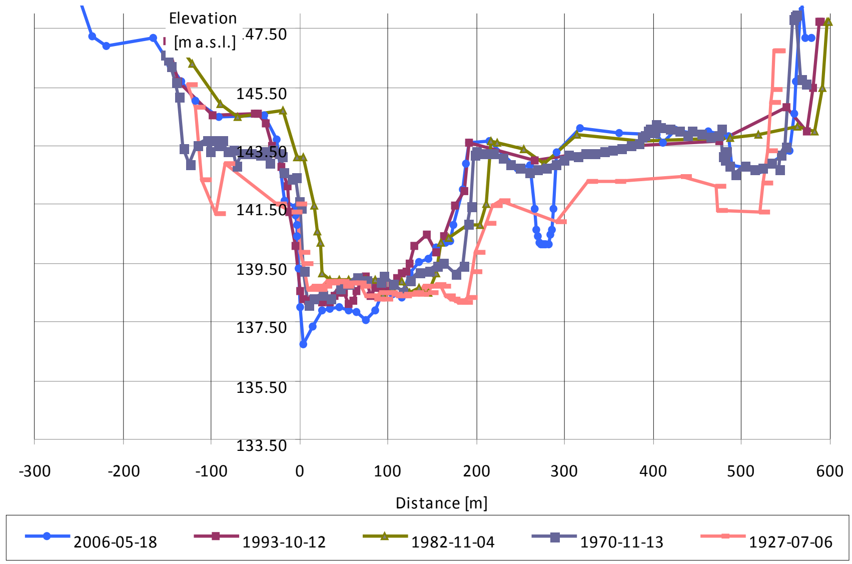

Figure 11. The channel geometry development in1927-2006 at the Sandomierz cross-section on the Vistula River [IMGW].

In the years 1969-1970 the Guidelines for Technical – Economical on the regulation of the Vistula River from the village Nagnajów (km 247) to the mouth of Sanna Stream (km 295) were developed. The purpose of this regulation was to maintain the suitable depth for shipping (about 1 m), protection against bank erosion and also to maintain the suitable condition for water intakes. The project was to be carried out in two stages:

first step: years 1970-1980: all the necessary works which were required for obtaining the suitable width of the channel,

second step: years 1981-1982: the complementary works concerning the new river channel strenghtening.

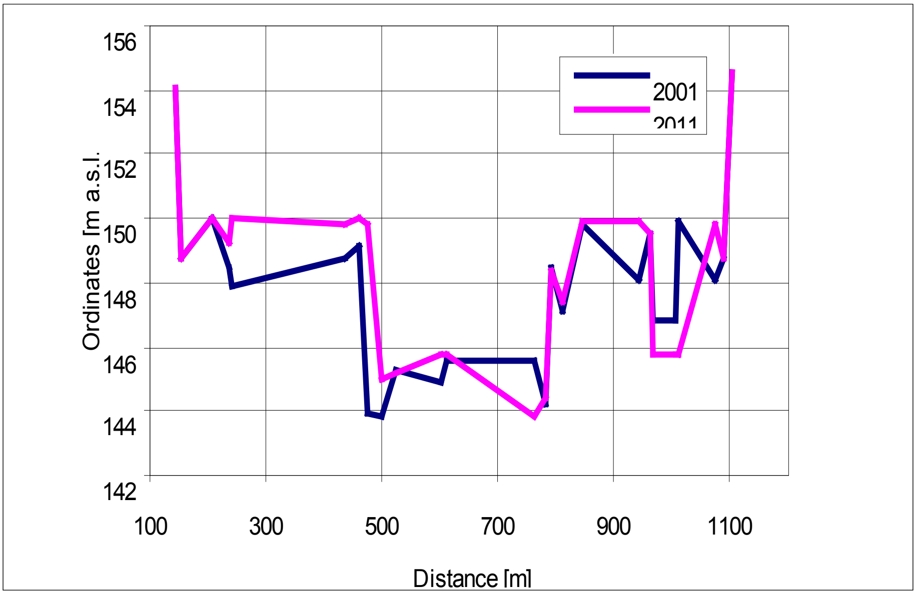

Figure 12. The channel geometry in 2001-2011 at km 249.000 on the Vistula River.

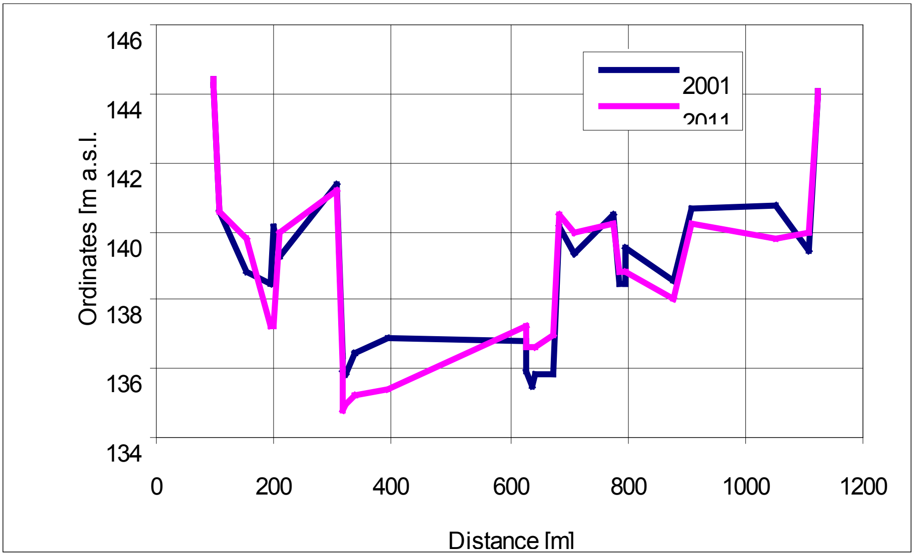

Figure 13. The channel geometry in 2001-2011 at km 282.600 on the Vistula River.

The impact of the above mentioned river training activities on the processes which occured through the new regulated river channel is visible. The analysis of minimum annual water stages at the studied gauging stations show that before the river training slight riverbed erosion or accumulation was observed. After the river regulation, since 1980, in Sandomierz and Zawichost the river channel has highly eroded. Now, the process of riverbed erosion is still observed but it runs with lower intensity (Fig.10, Fig.11). Unfortunately, it was impossible to carry out the comparisons and analyzes for the other five gauging stations, because measurements of water stages in these gauging stations were discontinued before the river training activities.

Formed new river channel for the flow of $Q=174\ m \cdot s^{-1}$ reached width of about 120 m is stable, and now there is not observed sandy dunes creation in the riverbed. In the places where the river channel has been widened because of the hydraulic structures destructions, currently there are observed dunes and sediments. In these parts of the river course the river channel geometry is variable as a result of sediment movement during the flood events. The sediment is transported and deposited in low-lying parts of the river, on the floodplains mainly, as it seen in the cross-sections located at kms: 247.700, 259.300, 264.000, 274.800 and 276.800 of the Vistula River course.

CONCLUSIONS

Observations and calculations of the riverbed erosion process in examined gauging stations indicate that erosion is a natural process, but its intensity is accelerated by anthropogenic factors.

On the basis of the minimum annual water stages analysis of the eight gauging stations of the Upper Vistula River it should be noted that since the beginning of the observation period, that is from about the beeginning of the 20^{th} century to the mid 1960's, riverbed erosion is observed with the slight tendency to accumulation.

As a result of technical river regulation in the 1970's on the Vistula river channel at kms from 247.000 to 295.000 in the Sandomierz and Zawichost gauging stations the proces of high riverbed erosion appeared. In 1980 the riverbed was lowered of about 50 cm. Presently the process of riverbed erosion is still observed there but its intensity is not high: in Sandomierz the mean annual riverbed lowering is 0.27 cm, and in Zawichost is respectively 0.9 cm per year.

In the examined gauging stations of the upper Vistula River also the impact of floods that occurred in the last decade on the analysed river course is observed. This can be seen in the result of the comparisons of cross-sectional geometry from the years 2001 to 2011.

In some cases it was observed, that in the cross-sections with sandy dunes, the riverbed is characterized by highly variable geometry as a result of the sediments movement. In the several studied cross-sections local significant lowering of the riverbed at the river banks were noticed. The magnitude of these lowerings reaches up to 1.8 m at some cross-sections, and the eroded sediment is deposited on floodplain terraces.

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dr inż. Marta Łapuszek
Cracow University of Technology
Institute of Water Engneering and Water Management
Warszawska 24, 31-155 Kraków
mlapuszek@iigw.pl